STEAM LABORATORY FOR THE GREATER ARMOUR INSTITUTE OF TECHNOLOGY

BY

J. H. CLOUSE

P. C. DUENNES

ARMOUR INSTITUTE OF TECHNOLOGY

1921

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A Proposed Design of the Steam Laboratory for the Greater Armour Institute of Technology

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A THESIS

PRESENTED BY

J. H. CLOUSE AND F. C. DUENNES

TO THE

PRESIDENT AND FACULTY

OF

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FOR THE DEGREE OF

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IN

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APPROVED:

Professor of Mechanical Engineering

Dean of Engineering Studies

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PART ONE

PREFACE.

In order to keep astride with the rapid development of engineering education during the last decade, the Armour Institute of Technology has deemed it necessary to erect a new institution with equipment adequate to the needs of a course in modern engineering.

The Steam Engineering laboratory on which this thesis has been written is only one of the many Engineering laboratories to be installed in the new building. It is intended to bring before the student examples of the various forms of steam apparatus used in modern steam power plants and to correlate the practical phase of engineering problems with the underlying theory learned in the class rooms. The purpose of the Engineering laboratories is not to furnish new and striking applications, as much as to explain in a simple and brief way every day methods of design, construction, use and operation; and to give the student a working knowledge in this branch of engineering. Spec-

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ial attention has been given to simplicity of operation and up to dateness of the apparatus in this laboratory.

While the authors have obtained much instruction from the preparation of the layout, they realize its defects. Any information that could be incorporated in the work and add to its usefulness to the student for whom it is intended would be of great value.

In the preparation of this work the authors have received valuable information from a large number of manufacturers and professors of Technical Schools, who have kindly and freely furnished drawings and data as called upon.

The authors wish to express their appreciation and thanks to them and especially to the following professors of the Mechanical Department at the Armour Institute of Technology.

Prof. G.F.Gebhardt.

Prof. E.S.Libby.

May 10th.1921. The Authors.

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PART TWO.

METHOD USED IN SECURING THE DATA.

Information concerning the design of this laboratory was secured for the most part by a study of our own present laboratory and also those in institutions of a similar character.

The method used in obtaining the data of this problem in detail is as follows: First, a rather thorough survey of the recent literature on the subject was made. Second, a list of the experiments as now given in the Junior and Senior year of the Mechanical Engineering course at the Armour Institute was prepared and carefully studied. Third, letters were written to about forty of the leading Technical Schools and Universities in the United States requesting information on the layout and design of their laboratories. Some of the typical replies are given on the following pages. Fourth, a preliminary layout was made in which is shown the apparatus

that would probably be used, also a general layout of the piping system. Fifth, letters were written to manufacturers of equipment to be installed explaining their use, probable size and operating conditions. From the replies and literature received, together with personal calls on the manufacturers, the equipment to be installed was selected.

Essential elements of typical replies from Educational Institutions:

Stevens Institute of Technology.

Regarding the Steam Engineering laboratory, we cannot be of much assistence to you, as our arrangement after twenty years service has become out of date. We are hoping to build and equip a new laboratory within a year and will be after the latest information on our own account. I am inclosing a few pages taken from our catalogue.

Carnegie Institute of Technology.

Our laboratory plans and equipment have had a varied and rapid experience. I shall

be glad to point out to you some of those experiences and mistakes.

Case School of Applied Science.

I have your letter of February 5th. and regret to say, that we cannot furnish you with any drawings or photographs of our laboratory, for the reason that it is rather ancient and the equipment is exceedingly crowded.

Sheffield Scientific School.

Yale University.

I want to say, that the policy of this laboratory is so different from that of others in regard to the temperary installation of equipment that no drawings or description can give an adequate idea of the making of a plan of the laboratory. It really should be visited to be understood.

PART THREE.

PRELIMINARY LAYOUT OF STEAM ENGINEERING LABORATORY.

The Steam Engineering laboratory can be separated into four distinct parts according to the arrangement of the equipment, and each part can be divided and subdivided according to the experiments.

These parts and divisions are essentially as follows:

1. Simple engines.
   - A. Valve setting.
     1. Simple D slide valve engine.
     2. Corliss engine.
     3. Marine engine.
   - B. Operation of a steam engine.
     Simple piston valve engine.

2. Modern comparatively large engines, and turbines.
   - A. Counter-flow engine experiments.
     1. Mechanical efficiencies.
     2. Water rate testing.
     3. Heat losses, etc.
   - B. Unaflow engine experiments.
     1. Comparison with other reciprocating engine economy.
     2. Heat losses.
     3. Mechanical efficiencies.
     4. Water rate testing, etc.
   - C. Turbines.
     1. Comparison with engine economy.
     2. Water rate testing.
     3. Efficiencies.

3. Condensers.
   A. Leakage tests.
   B. Condenser losses.
   C. Vacuum variations.

4. Testing Instruments.
   A. Calorimeters.
      1. Throttling.
      2. Separating.
   B. Calibration of gauges.
      1. Pressure gauges.
      2. Vacuum gauges.
   C. Calibration of thermometers.
   D. Steam indicator calibration.

With this group arrangement of apparatus and knowing the experiments which come under each group the particular apparatus to be used in connection with them was then selected. However in making the selection it was found that a portion of the apparatus would undoubtedly be duplicated in the Hydraulics laboratory and to a slight extent in the Air laboratory.

After consulting the designers of the Hydraulics laboratory, it was decided to correlate them. Since the apparatus in the Air laboratory would only be duplicated to a slight extent in the steam laboratory, it was decided not to connect them.

The plan of putting the Hydraulics

with the steam laboratory proved to be very satisfactory. It was found that some apparatus was essential to the Hydraulics laboratory for pumping purposes could be in the steam laboratory and be actuated by steam. This same apparatus then could be used for certain experimental determinations which pertained essentially to steam, thereby prevent duplicating the apparatus.

The apparatus which was used in conjunction with the laboratories were, piston pumps, turbine driven centrifugal pumps and injectors.

On the following page will be found the preliminary layout of the Steam laboratory as originally designed.

SKETCH OF STEAM LABORATORY.

HYDRAULICS LABORATORY.

Steam injectors

Balcony

Boiler

Boiler

Calorimeter testing

Boiler

Steam calorimeter

Horizontal piston valve engine.

Uniflow engine

Prony brake dynamometer

Kerr turbine driving C.&T. pump.

Horizontal belt driving dynamometer

Two stage air compressor

Horizontal engine

Uniflow engine with indicator & dynamometer

Curtis belt driving C.&T. pump

Engine & generator

Cross compound slide valve engine

Air compressor

Air receiver

Air pump

Condenser

April 12, 1902.

PART FOUR.

SELECTION OF EQUIPMENT.

THE UNAFLOW ENGINE.

THe advent of the unaflow engine and the principles upon which it was based constituted an epoch in steam engine building. Steam engineering was practically at a stand still, as no improvements which gave any substantial gain in economy had been made in twenty years. Development in power engineering seemed centered on internal combustion engines and large condensing steam turbines.

With the average engine using, under ordinary non-condensing conditions with saturated steam, from 30 to 50 pounds at full load and from 70 to 100 pounds at one quarter load after a few years of service the arrival of the unaflow engine with its steam rate of under 19 pounds from one quarter to full load non-condensing and under 14 pounds at all normal loads condensing both without superheat, completely reversed the situation when it was realized that the unusual economies guaranteed

could actually be obtained.

Now, unaflow engines are supplanting oil engines, condensing and non-condensing steam turbines and all other types of steam prime movers.

The unaflow principle has for its object the elimination of one of the greatest losses in reciprocating steam engines, namely, initial condensation.

With the unaflow engine, the steam enters the cylinder at the ends, after passing through steam jacketed heads and after cut off and expansion have taken place, the steam is exhausted through ports arranged around the center of the cylinder, which are uncovered by the piston at the end of the stroke. The steam has consequently a flow in but one direction, hence the derivation of the phrase "unidirectional flow".

In the counterflow engine the steam returns on its path at the end of the stroke and is exhausted at the same end of the cylinder at which it enters. By this method, the cold expanded steam of considerable volume washes the cylin-

der walls and head during 50 to 75 percent of the return stroke, thereby cooling them to such an extent that the boiler steam, when it is again admitted, is cooled or condensed by coming in contact with the head and clearance spaces of cylinder which have just been cooled by the expanded exhaust steam.

It is this cooling effect that causes what is termed "initial condensation", which is almost entirely eliminated in the unaflow engine, where the ends are kept hot and the center or exhaust left cool.

It was to remedy this fundamental defect of the counter-flow engine that expansion stages were resorted to, as in compound or triple expansion engines. Superheating has also been employed to over come the above mentioned difficulty, but superheating cannot be effected without some cost in installation and operation and much of the apparent gain in engine due to superheating is counteracted by increased boiler efficiency.

Now by avoiding the cooling of all

clearance surfaces in the design of the cylinder itself, it is possible to obtain in a single cylinder as many expansions with as good or better economy as can be obtained in any compound, or triple expansion engine.

Therefore because of its recent development, unusualeconomy and high efficiency, the unaflow engine is very desirable for laboratory analysis.

Two typical unaflow engines have been selected for the laboratory and a brief summary of the specifications for each is given on the following pages.

SPECIFICATIONS OF "THE UNAFLOW ENGINE"

The cylinder really consists of two single acting cylinders set end to end, with a common exhaust. In operation, steam is admitted to the cylinder by the double beat poppet-valve of special construction to insure steam tightness, which is lifted by a roller in the sliding bar when it comes in contract with the lifting cam and the valve is closed by the spring on top of

the bonnet with lower end resting on top of a circular crosshead to which the lifting cam is rigidly bolted.

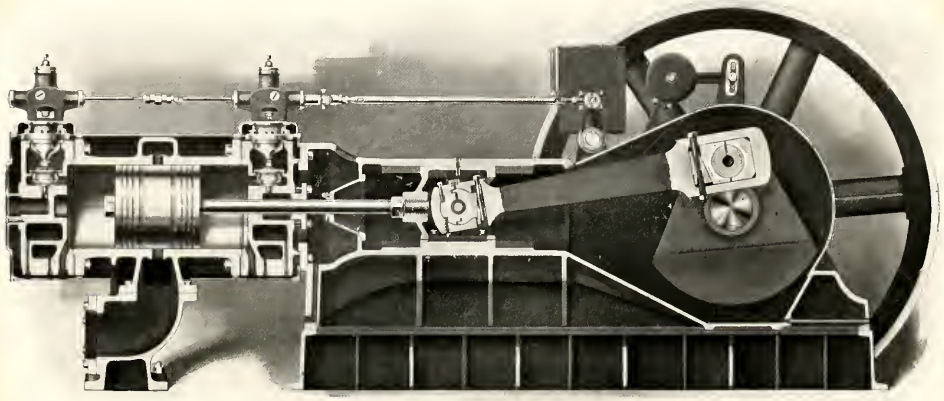
The admission valves being of the double poppet type, with upper seat flexible, will always remain tight. The construction of the bonnets and detail of the valve gear is very simple. The valves are lifted in perfect alignment from their seats so when the engine is operating at maximum cut offs, the valves and cams are perfectly noiseless. The valve stems operating in long sleeves made it unnecessary to provide any other packing.

The piston is long enough to keep the central ports covered until the exhaust occurs, which is nearly at the end of the stroke. These central exhaust ports open directly into a central exhaust belt encircling the cylinder from which direct communication is made with the exhaust pipe or condenser connection.

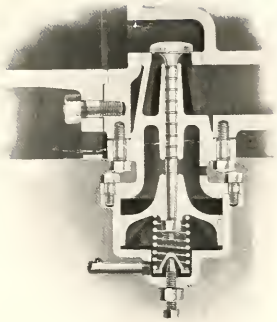
The cylinder heads are made of hard close grained iron of the same mixture as the cylinder casting and are annealed so that all initial strains are eliminated. The heads contain the steam admission

valves, with the steam port which is very short and direct, admitting the steam into the cylinder as near the center of the end of the piston as possible. This construction eliminates any possibility of wire drawing the steam through long indirect, or restricted ports and passages after leaving the throttle. The heads are lagged with magnesia lagging of sufficient thickness to insure proper insulation and this is covered with a smooth sheet metal casing secured to the head in a manner that makes it unnecessary to disturb the magnesia lagging when removing cylinder head.

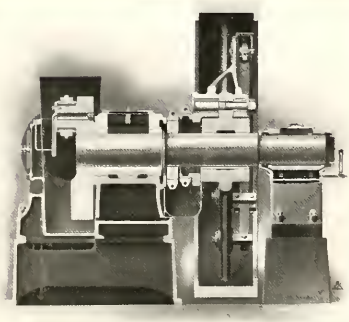
Engines furnished for condensing operation are equipped with the automatic by-pass valves, shown in section, to prevent undue compression in the cylinder due to loss of vacuum. It will be noted that the construction is of the simplest possible form and the automatic operation of the by-pass valves is entirely controlled by existing conditions in the exhaust belt of the engine. These conditions being communicated from the exhaust-belt of the engine



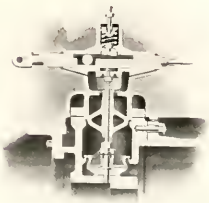
Longitudinal Section Through Engine



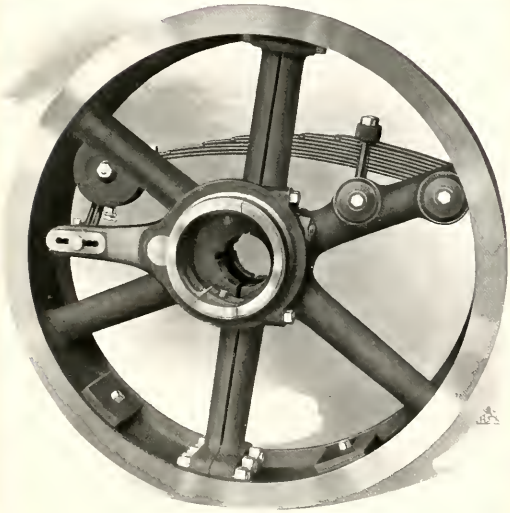
Section Through Automatic By-Pass Valve



Vertical Section Through Main Bearing and Governor



Section Through Admission Bonnet
and Valve



Automatic Governor

to the valve piston through the small pipe connection between the exhaust-belt and the piston chamber.

The improved Robb-Armstrong-Sweet governor is a perfect regulating device. It is carried in a heavy flywheel, is simple and durable in construction and staple in operation under all conditions of service. The split wheel has planed points fitted together with a tongue and groove and secured by heavy bolts in rim and hub.

The lubrication of the piston and cylinder are provided for by a mechanically operated double-feed cylinder lubricator of large capacity. One feed is connected to the throttle-valve through which a small amount of oil is fed to sufficiently lubricate the valve stems. The other feed is connected to the cylinder and the oil for lubricating the piston is fed directly into the cylinder.

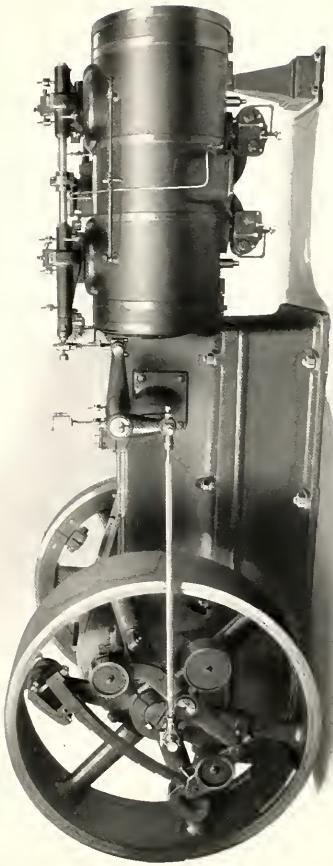
The main bearing, crosshead, crosshead pin, crank pin, rocker-arm shaft and eccentrics are lubricated from the automatic oiling system which is furnished on all engines.

SPECIFICATIONS OF "THE SKINNER UNIVERSAL UNAFLOW ENGINE.

The auxiliary exhaust valves open and close under no difference in pressure on either side of valve. This, in itself, is a novel feature, never having been employed before in steam engine comstruction and possesses some distinct advantages.

The easy conditions of operation of these valves permit the employment of a single seated poppet valve, which requires less clearance than a double-seated valve which would have been necessary if the valves were to open and close against pressure. It allows the use of an extremely simple and compact driving gear, upon which there are no strains. A spring of but small tension is required. In fact the valve has been operated without any spring whatever.

Double-beat poppet exhaust valves placed at the ends of the cylinder are subject to leakage due to the pitting action of the warm condensate filling the exhaust cavity when the engine



The Skinner Unaflow Engine

is not operating. Moreover, the seats of these valves must be flat, which hastens leakage by the pitting action. This is impossible with the single-bevelled-seat poppet valve located as it is in the "Universal Unaflow" construction. The clearance in the auxiliary exhaust ports is less than one percent.

The spring is telescopically mounted around the valve stem, in order that the entire exhaust gear may be above the floor and accessible.

When operating condensing, the auxiliary exhaust valves are automatically disengaged and remain closed at all times unless the vacuum should break, whereupon the valves are automatically placed in operation and the engine therefore becomes a noncondensing unaflow engine again.

Other engines must be designed for either condensing or noncondensing operation and their economy under the condition for which they were not designed will be poor. A compromise in the cylinder ratio of a compound engine for condensing and noncondensing operation will result

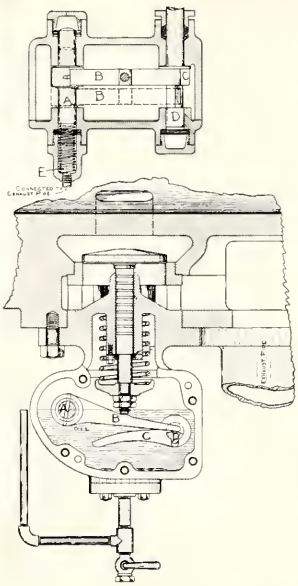
in poor economy under both conditions.

Moreover, so far as the "Universal Unaflow" engine is concerned, the change is made autom tically, no readjustment of any kind being required.

The cross section drawing shows the construction of the patented auxiliary exhaust valve gear and automatic disengaging device.

A is the shaft supporting idler B, which is operated by shear cam C. This cam is operated by the engine valve gear which is connected to shaft D on the outside of the cam box.

When the cam C raises the idler B, the latter raises the single-beat exhaust valve the stem of which projects within a short distance of the idler B. The spring around the valve stem has only enough tension to insure quick closing when operating at high speeds. The shear cam is so designed that there is practically no sliding action on the idler. Both cam and idler are of steel and are im-



Cross Section Auxiliary Exhaust Valve Gear

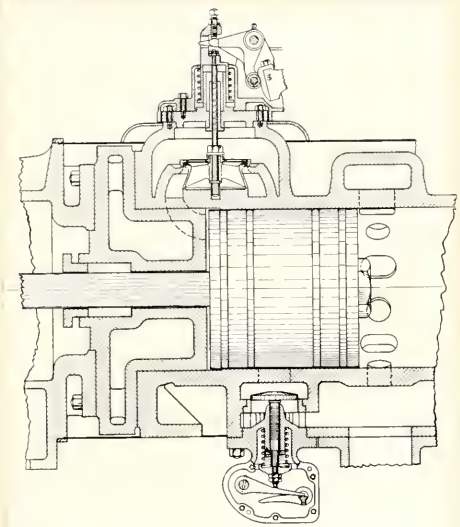
mersed in oil.

The pocket E is connected to the central exhaust port by means of a small pipe, and the function of the spring in this pocket is to keep the idler, through its attached shaft, in register with the stem of the valve and the cam C directly underneath.

When the vacuum reaches a predetermined point, it overcomes the tension of the spring in pocket E, and draws the shaft into the pocket. This in turn shifts the idler to position B and out of register with cam C, so that while the cam still operates as before, it cannot lift the valve.

Therefore, the valve remains closed at all times when vacuum exists in the exhaust pipe and is kept tightly closed by the pressure in the cylinder on top of the valve, as opposed to the vacuum on the under side of valve.

The cam C is so designed that the idler B is always supported by it, the support



Cross Section Admission Valve Gear

when the engine is running condensing being on the idler part of the cam, and no movement is transmitted to the idler. The idler is therefore held at the proper height so, that if the vacuum fails, the spring, now asserting its force in the pocket E, will slide the idler between the lifting face of the cam and the valve stem, whereupon the auxiliary exhaust valve begins its functions and the engine automatically becomes a noncondensing engine. The auxiliary exhaust valves are provided with labyrinth or water-groove packing.

The valve gear is capable of operating at comparatively high speeds and at the same time eliminating the side pull of the cam against the valve stem when the valve is being raised. This side pull has caused annoyance and trouble on other existing poppet-valve gears, and the large guides which are now provided in those gears do not prevent side wear and consequent lost motion.

The admission gear consists of one rocker arm, with case hardened removable steel cams which dip into the oil bath and control the

operation of the valves by means of forked lef-levers or lifters, on which are mounted case hardened rollers bearing against the cams.

It will be seen that the valves are lifted without imposing any side strains on the stem. The formation of the dam is such that the roller is always in contact with it. Therefore the valve is lifted and seated quietly, even at high speeds.

The adjustment of the valve, cam and lifter is the simplest that has ever been constructed, being made by one set screw located above the lifter. Adjustments can be made while the engine is in operation.

Instead of mounting the spring above the valve, as it is customary, it is telescoped in the housing, but of course not in the steam space, and presents a compact and neat appearance.

Labyrinth or water-groove packing is used which will maintain its steam-tightness without attention for years.

The poppet valve has been adopted

for the "Universal Unaflow" engine because for high pressures and superheat, which prohibit the use of a sliding or rubbing valve, the poppet valve provided the nearest approach to steam tightness after years of use.

Solid poppet valves when ground for a certain steam pressure and temperature, will remain steam tight indefinitely, providing the pressure *and* temperature is not allowed to vary, but if the pressure or temperature should vary and it is next to impossible to prevent their changing, the difference in the coefficients of expansion of the two metals forming the valve and the seat in the cylinder will cause the one to expand more than the other, resulting in either the upper or the lower part, of the valve not making contact with its seat in the cylinder.

The upper part of this valve is not rigidly connected to the lower part, but allows an expanding and telescopic action and comes in contact with its seat shortly before the lower part, with the result that both seats make steam tight contact irrespective of the difference in

expansion of the cylinder and valve metal.

THE CROSS-COMPOUND CORLISS POPPET FOUR-VALVE ENGINE.

When it became apparant to engineers that higher pressure steam and higher temperature steam were the logical developments, it became necessary to change and improve the designs and construction of engines to utilize the increased pressure.

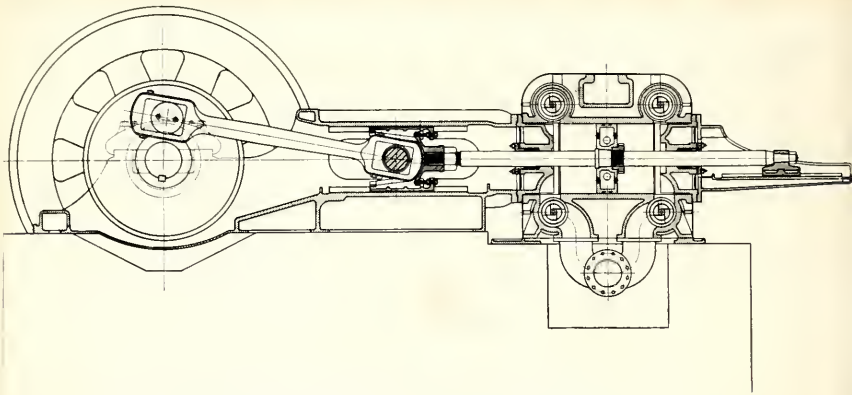
In America, England and France, the corliss engine, with its valve admirably suitable for lower steam pressure and low rotative speeds, was accepted as standard up to recent years, but engineers in Germany, Austria and Switzerland worked on the development of the poppet valve fifty years ago. They foresaw the advent of higher steam pressures and temperatures and subsequent events seem to show their judgment was right. In the sixties of the past century the first poppet valve engine appeared on the market. It was designed by a young Englishman, Charles Brown, chief engineer of the famous firm of Sulzer Bros. of Winterthur, Switzerland.

When other prime movers threatened to affect the market for steam engines, when greater rotative speeds were demanded to meet the insistent cry for great production, designers here and everywhere turned to the poppet valve engine, which offered a solution. Therefore because of the recent development of corliss engines along this line with increased economy, it will be advantageous to have an engine of this kind in the laboratory.

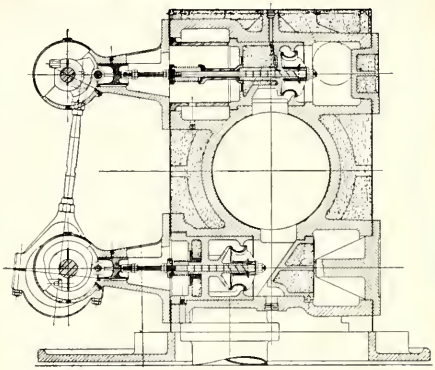
SPECIFICATIONS OF HAMILTON POPPET FOUR- VALVE ENGINE.

It was obvious that complicated valve mechanism and trip gears could not be used successfully on high speed engines, for the hard service would create, excessive wear that they could not survive.

The poppet valve is operated by a lay shaft running along the side of the engine driven from the main shaft through a drag crank and shaft by means of a pair of spiral gears. The drag crank is self adjustable and prevents the unavoidable motion and jars of the main shaft from being transferred to the valve gears, which



Longitudinal section of the Hamilton Poppet Four-Valve Engine, showing tail rod construction. Note the ready accessibility of the piston.



Cross section of small Four-Valve cylinder. This construction is used on engines too small to accommodate the internal cam arrangement shown in the above cut.

consequently operate without noise, which means with the minimum of friction and wear.

The lay shaft is placed in line with the exhaust valves, the bonnets of the exhaust valve gear being provided with bearings to support the shaft. The exhaust valves are operated by cams acting on anti-friction rollers, effecting a rapid opening and closing. The cams are clamped on the shaft and can be shifted into any position to give the desired release and compression.

Oscillating cam levers acting on rollers attached to the valve spindles operate the steam admission valves insuring ample and quick valve openings as well as noiseless operation even at the smallest cutoffs.

The oscillating levers for both admission valves are mounted on a single shaft which receives its motion from the eccentric rod and eccentric mounted on the lay shaft. It is noteworthy that this arrangement of the Hamilton poppet-valve gear necessitates the use of but one single eccentric and strap and rod instead of the four

eccentrics usually provided in other types of poppet valve engines.

The valves are placed in a horizontal position, well supported by long spindles and guides. The valve spindles are carefully ground into long bushings and provided with a labyrinth packing consisting of small circular grooves.

The effective method of lubrication and ample support prevent any bending stresses in the spindles and minimize the possibility of wear. The horizontal position of the valves and seats is of distinct advantage, for the seats are cleaned during every steam admission period, which makes an accumulation of burnt oil and sediment impossible.

Of particular interest is the design of the valve cages which contain the valve seats and spindles and the complete structure of the ports. This is a distinct improvement over the usual rib design with its large clearance surface and volume and its unequal expansion when subjected to operating temperature.

The cage design insures a perfect casting with a reduction in clearance space not obtained in any other design. The whole valve assembly is easily accessible by simply removing the back covers without interfering with the valve gear.

The valve gear parts work in a removable cover preventing the ingress of dirt, and operate in an oil bath through which the oil may be circulated continuously and used over and over again. Absence of wear, and reliability of operation of the valve gear is further insured by this arrangement.

The different load conditions of operation are counteracted by the use of a shifting eccentric which operates the steam valves. A slide block is keyed to the shaft and the eccentric arranged slidable on it, connected to and controlled by the shaft governor. The eccentric is so shifted that the throw increases according to the requirements of the load while a practically constant speed is maintained.

The shaft governor provides large centrifugal forces which make the governor sensitive yet powerful enough to withstand the reaction of the valve gear. The governor, perfectly balanced consists of two pendulums which by means of toothed segments, shift a sleeve mounted on the shaft. This sleeve, in turn is connected to and shifts the large eccentric.

A hand speed adjustment permits a change of speed up to 50% while the engine is in operation.

A very effective method of lubrication is provided for the eccentrics, eccentric strap and governor.

Such parts as cams, rollers, pins, bushings, etc. in the valve gear and governor are made of machine steel and case hardened in order to prevent wear.

A metallic packing is provided for the piston rod consisting of cast iron rings arranged to follow the floating action of the piston rod. The packing effectively prevents the escape of steam under all conditions of pressure and superheat.

TWO STAGE AIR COMPRESSOR.

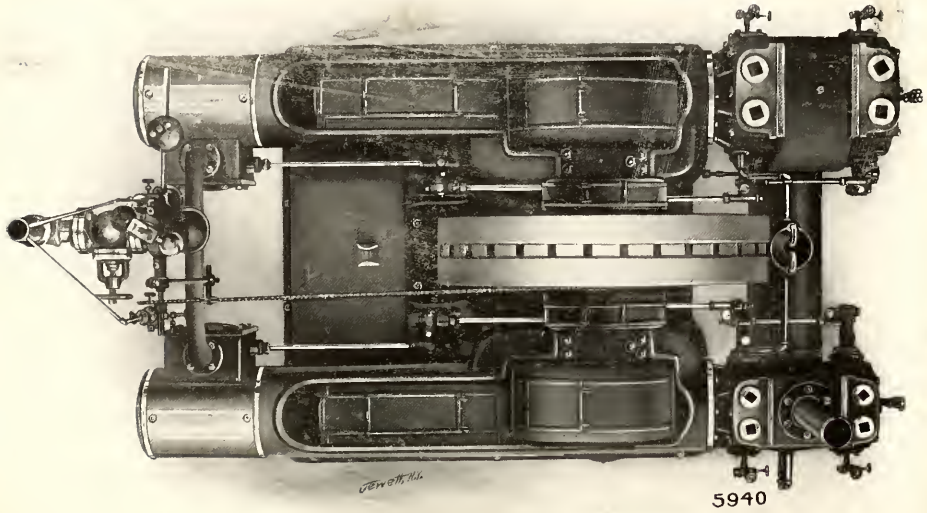
The inherent economy of high pressure superheated steam has led during recent years to its extensive adoption and its ever-increasing popularity as a source of power.

Recognizing the growing demand for a steam driven air compressor designed and constructed to operate satisfactory under high pressures and superheat, certain important changes have been embodied in steam driven compressors to meet these new conditions.

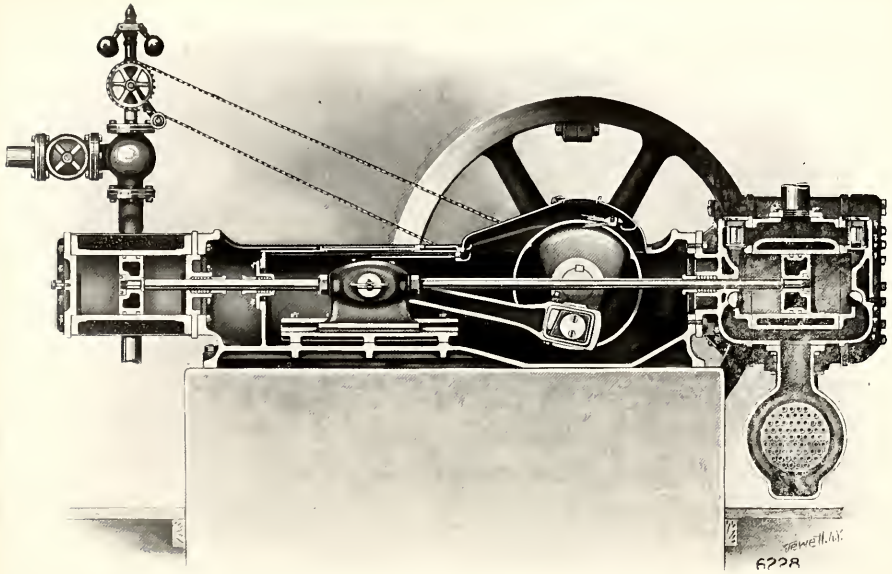
The "Imperial A" compressor built by the Ingersoll-Rand Company is an "all around machine". It is moderate in first cost, low in operating and maintenance charges, compact in design, as nearly automatic as possible and thoroughly reliable under whatever conditions of service. It is a very suitable unit for laboratory analysis.

SPECIFICATIONS OF "IMPERIAL X-2"
DUPLEX STEAM DRIVEN AIR COMPRESSOR.

The sensitive and quick-acting reg-



Looking Down on an "Imperial X-2" Compressor



Section Through High-Pressure Side of "Imperial X" Compressor with Underneath Intercooler Standard Construction on Machines of Light 16-inch Stroke and Smaller

ulating devices and the novel system of lubrication makes this compressor as automatic in action as a machine of this type can be. The design permits almost every possible combination of driving and compressing elements. These features combined with the large air capacity, have made the "Imperial" type one of the most popular machines for all classes of service, but particularly for conditions demanding great capacity and perfect reliability combined with minimum dimensions and automatic operation.

"Imperial" compressors with plain slide valves have a fixed cut off whatever the pressure. "Imperial" compressors with Meyer adjustable cut off which is best for the particular pressure carried.

The steam expansion, therefore in either case is practically constant regardless of the speed and compound economy is always practically maintained whatever the load. Experience has shown that where these machines can be run condensing, it is well worth while

to compound the steam cylinders on steam pressures as low as 80 pounds gauge. Running non-condensing, however, 90 pounds gauge is about the lowest initial pressure with which compounded steam cylinders can be profitably used. Below these pressures, simple steam cylinders probably give as good economy as can be expected.

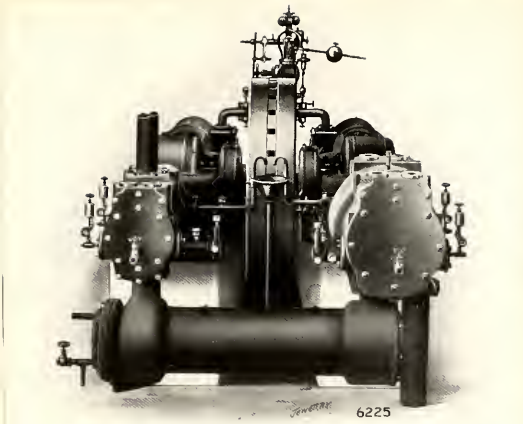
The advantage of compound steam cylinders lies in the higher expansion thus secured. The degree of expansion is determined by the initial and terminal pressure. The initial pressure is, of course fixed by the boiler pressure, but the terminal pressure depends upon whether or not a condenser is used, and upon the degree of vacuum obtained. With low steam pressures, noncondensing compound steam cylinders are not advisable.

The air cylinders of all "Imperial" compressors are designed for maximum compression efficiency. Barrels and heads are water-jacketed, the latter being hooded for the admission of cool, clean air. Both inlet and

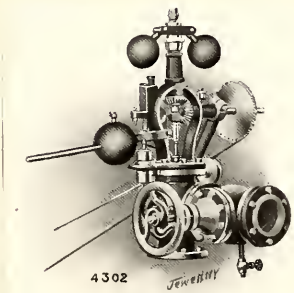
discharge valves are in the cylinder heads.

The air intake valves are of the well known "Imperial-Corliss" type, operated from eccentrics on the main shaft. These valves are of unusually large diameter and provide the shortest and most direct passage for the entering air, with the minimum of clearance. The working pressure is evenly distributed over the entire valve surface, which is almost exactly a half circle and this pressure being always central, there is no tendency to wear either the edges or the surfaces with which they come in contact. The valve adjustments are so fixed they cannot be disarranged by an incompetant attendant. The valve movement is properly timed to admit, and to keep in a full cylinder of air at each stroke.

"Imperial X" compressors are controlled by an Air-Ball governor which is a combination of reliable fly-ball speed governor with a pressure cylinder connected with the air receiver and acting upon the balanced valve of the regulator. The governor is driven by a chain from the shaft.



Air End View of a Small "Imperial X-2" showing Underneath Intercooler



The "Air-Ball" Governor

The fly-balls determine the maximum speed of the machine, and if the supply of air exceeds the demand, thus increasing the receiver pressure, the pressure element of the combination reduces the speed by throttling the steam until normal air pressure is restored. The action of this governor, while immediately adjustable to any pressure required, is always automatic and reliable and both the steam consumption and the air delivery are proportioned to the requirements of the movement.

DIRECT CONNECTED CORLISS ENGINE.

It is often very essential that a current of constant voltage be supplied for certain experimental work in the Electric laboratories and it is often very difficult for the engineer in the power plant to supply such a current because of the constant varying load conditions of the school. So consequently a direct connected unit would for this reason be very desirable in the laboratory. The generator of the unit could

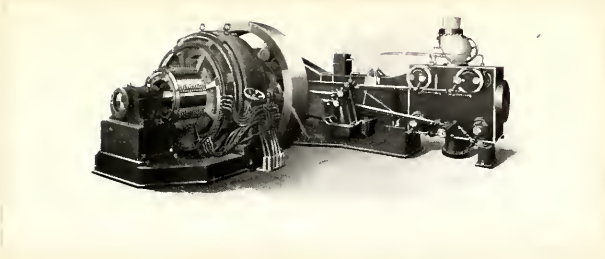
also be used as a form of electric dynamometer and experimental tests be made on the engine part of the unit by this method. And equipment of this kind being complete in itself having an exciter switch-panel, etc, would be very applicable for experimental work in the electrical engineering course and would give the student a working knowledge of the operation of a small steam power plant.

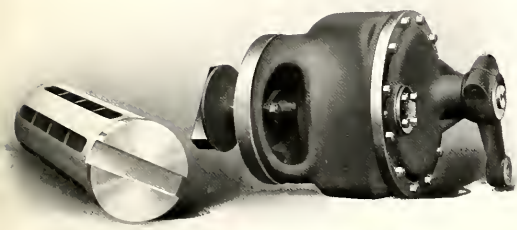
It would be very desirable to have a corliss non-releasing gear type of engine representing a different design in steam engine construction in the laboratory.

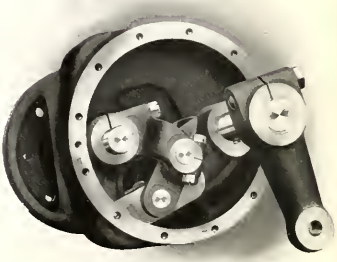
On the following few pages is given in brief the essential specifications of a non-releasing gear corliss engine manufactured by the Ball Engine Company.

SPECIFICATIONF OF THE BALL NON-RELEASING GEAR CORLISS ENGINE.

The frame design is such as to give the greatest strenght and rigidity. Under the heaviest loads there is no preceptible evi-







Valve Gear

dence of strain. This is accomplished by a most careful and scientific disposition of the metal, as well as by its use in unstinted quantity wherever weight is of benefit.

The ball automatic oiling system provides a cool, clean supply of oil, which is fed to all principal bearings of the engine. Adjustable sight feeds of liberal size are provided at each bearing, and these are piped together and coupled to a tank mounted on top of the engine and arranged to also act as a filter. The oil is automatically returned from the crank pit to the filtering tank by a pump of such design that the suction and discharge ports are positively opened and closed at the proper time. It has no valves and cannot be clogged by waste or foreign substances, as is possible with usual types of pumps. It affords a most reliable means of supplying oil to the bearings. The advantages of having an oiling system not liable to interruption and capable of supplying oil in any quantity desired, are very great, particularly where the service is hard and continuous.

The means employed for carrying the end of the eccentric rod and the valve stem is often a source of considerable annoyance after some wear has taken place. In this engine there is a rocker arm of novel design, which makes no trouble whatever. It has a self aligning bearings of hard and durable material, and these bearings run submerged in a bath of oil. In consequence they require no attention and while adjustments are provided, they are not needed for years.

Neat and substantial reducing motions for taking indicator cars are provided with these engines, when ordered. They are so designed that it is not necessary to leave off the side plates on the engine when using them. They give a correct reduction of the motion, and means are provided for conveniently connecting and disconnecting them when taking cards.

The shaft governor which is used to control all of the engines, both single valve and corliss types, is universally recognized as being the most simple and efficient governer ever built.

The speed is raised or lowered by changing the tansion of the spring. The sensitiveness is controlled by moving the link which connects the weight and the eccentric, in or out along a row of holes provided for that purpose. Moving it in towards the shaft increases the sensitiveness. These two simple adjustments, one controlling the speed and the other the regulation, are positive in their action, very easily made and when made are permanent.

This governor is exceptionally well adapted to engines driving alternating current generators in parallel. This governor has little friction and that little is of uniform character, making it possible to throw one engine in parallel with the other by use of the throttle. With this type of governor the engines are so easily thrown in parallel that no speed changing devices for synchronizing are needed.

The steam valves are of the corliss type double or triple ported, according to the size of the cylinder. The design is such that the supporting area is constant for any position of the valve

and on account of the resulting elimination of wear these valves remain tight for a long period of years.

The Armstrong non-detaching valve gear by positive action gives the valves the same movement as the drop cut-off gear does by picking up and dropping them. It opens and closes the valve at the proper time and in the remainder of the time, or over half a revolution, it holds the valve still but doesnot let go of it. The valves require but a small movement to open them and the compression helps to balance them at that instant. They are balanced during the time they are open by reason of the pressure being the same in the steam chest and the cylinder.

They are also nearly balanced while closing, providing they are closed quickly before the steam expands to a much lower pressure. Then for over half of the revolution the valve is very much unbalanced and it is necessary for durability and tightness, as well as for the most satisfactory operation, that the valve remain motionless during this period.

The requirements for an ideal gear for engines of this class are very exacting and difficult attainment. This valve gear fulfills them, and not only gives the valves the motion necessary for the greatest durability and continued tightness, but also makes possible the use of the best type of valves, as previously explained.

The gear is enclosed in a tight case, which is partly filled with oil. The shafts and pins are of hardened steel, ground perfectly true and smooth. The bearings are of hard phosphor-bronze. All parts are interchangable and cheaply renewable, and the whole construction is of the highest grade. The design is such that all stresses are central with the members, and there are no twisting stresses to disturb the alignment of the bearings.

The exhaust valves close off the ports on both sides of the valve and so reduce the clearance space. The design is such that there is the least possible wear and no tendency whatever to wear in such a way as to make them leaky.

All the corliss engines are supplied

with relief valves built into the cylinders in such a way as not to affect the clearance. These valves are unusually large and afford all the protection that it is possible to obtain by this means.

For economy, regulation, durability and fine running qualities, these engines mark the very highest standard of excellance. They have given ample evidence of their superior ability to meet the demands of the most exacting grades of service.

STEAM TURBINES.

Within the last few years the use of the steam turbine has increased rapidly. Much of the auxiliary apparatus installed in power plants is adaptable to direct driving by steam turbines, particularly centrifugal boiler feed pumps, circulating pumps, hot well pumps, centrifugal blowers for forced draft, centrifugal air compressors, etc. Centrifugal and high speed rotative vacuum pumps are coming into use and by means of gears, belts or ropes the turbine can be adapted for driving

slow speed induced-draft fans, stokers, coal and ash conveyors, reciprocating air pumps, and similar equipment.

Whenever apparatus can be directly driven, the steam turbine is unrivalled, and in contrast to the ending, maintaines a good steam economy indefinitely. It is simple and compact, and few wearing parts are readily accessible for repair. Little attention is required other than to see that the bearing reservoirs are kept filled with oil.

For close speed regulation the turbine is unexcelled. Overloads are carried without stress or harm to the turbine.

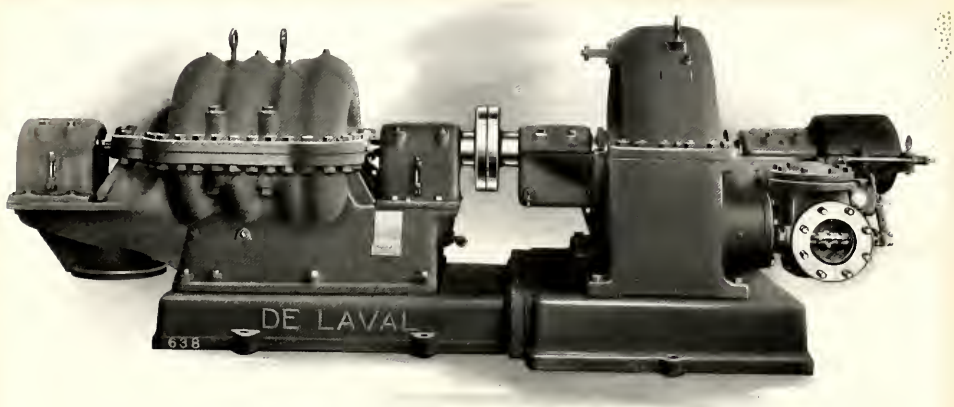
Now because of the recent development of the turbine as a source of direct motive power and its wide application in the steam power plant, it is quite essential that the turbine be part of the equipment in a modern steam engineering laboratory.

Two types of steam turbines are listed on the following few pages and a brief summary of the important specifications are given for each.

SPECIFICATIONS OF CLASS "C"DE LAVAL
VELOCITY-STAGE TURBINE.

The class "C" tubine is designed for direct connection to centrifugal pumps and blowers, small alternating or direct-current generators, centrifugal air compressors and other moderate or high speed machinery.

It is peculiarly fitted to operate with high pressure steam exhausting to atmosphere or against back pressure or with low pressure steam exhausting to condenser, but it is also built to operate with high pressure steam when exhausting to condenser and as a mixed-flow turbine receiving both high and low pressure steam and exhausting to condenser. Also especially designed to secure simplicity, accessibility, reliability and safety. All interior parts are accessible upon lifting the casing cover and without disturbing steam or exhaust connections. All parts subject to wear, such as nozzles, buckets and guide-vanes are independently renewable without necessitating renewal of larger expensive parts. A short, thick



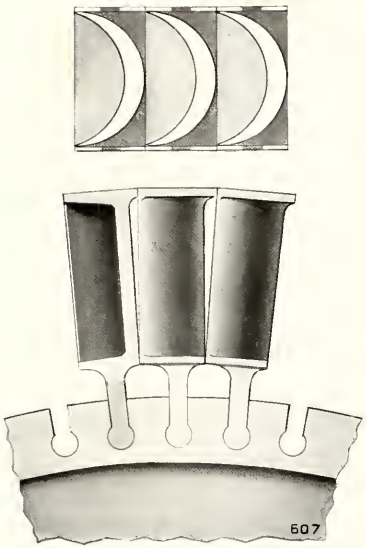
Class "C" Turbine directly connected to De Laval Three-stage Centrifugal Boiler-feed Pump.

shaft is used to prevent vibration and the wheels are surrounded by an impenetrable steel armor.The wheels together with the manner of attaching the buckets, form a most important element in turbine design.

The wheels of De Laval class "C" turbines are forged steel disks, finished and polished on all surfaces and designed to withstand safely rotative speeds far in exeess of the normal speed of the turbine. They are centered on the shaft by ground disks and are secured by Woodruff keys.

Aside from shaft bearings and valves,the only parts of the class "C" turbine that are subject to wear are the buckets and guide vanes.The prevention of wear of such parts is largely a matter of supplying dry steam and of using proper materials having suitable finish.

The buckets of De Laval class "C" turbines are made of nickel-bronze by this process and are secured to the rim of the wheel by bulb shanks inserted into slots milled transversely to the plane of the wheel a mode of attachment which develops the full strength of the bucket



Method of fastening De Laval Buckets in rim of Turbine ***Wheel.***

and at the same time permits removing or replacing individual buckets without disturbing others. The buckets are not riveted to a shroud ring nor are they pinned or riveted in the rim of the wheel itself. The driving fit used for holding the bulb shanks makes the replacement of buckets a simple matter, without danger or distortion or unbalancing of the wheel. This result depends upon careful and exact work in the formation of the bulb and of the slot, and the only excuse for riveting bulb shanks in the wheel rim is inaccurate work in machining the parts. The shape of these buckets utilitizes the full cross section of the material for resisting centrifugal force by tension and is to be preferred to all methods in which parts of the buckets or rim are subjected to bending stresses.

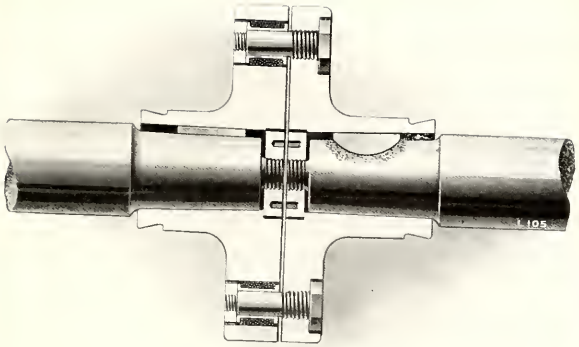
The bucket tip has front and rear projections which touch the adjacent buckets, forming a continuous rim which serves to retain the steam jet and prevent spilling, reduces the fan action of the buckets and prevents movement or vibration of the individual buckets.

A separate wheel is provided for each row of buckets in order to avoid straining the disks by a wide, overhung rim. The several wheels carrying the individual rows of buckets are placed close together, being spaced by a collar on the shaft and held in place by a lock nut.

The method of governing adopted in the De Laval class "C" turbine is by throttling, with auxiliary hand control and gives the maximum economy, while at the same time retaining simplicity.

Three types of speed governors are used according to the size and speed of the turbine and character of the driven machine.

The simplest in construction is the shaft governor, consisting of two weights mounted upon a governor head, both weights and head being cut from solid pieces of steel. The weights are hinged on hardened knife edges and require no lubrication. The governor weights in moving outward press on a spindle, pushing the latter outward and compressing a spring. This spindle in turn operates the throttle valve through which steam is admitted to



Section of De Laval Flexible Coupling. This coupling is used between all Turbines and Driven Machines, and between the Gear and the machinery to which the Gear is connected.

the steam chest of the turbine. The valve is of the balanced double seated, mushroom type, carefully adjusted to remain tight and balanced under all steam conditions. Where superheated steam is employed, the valve and seats are made of steel or nickel composition.

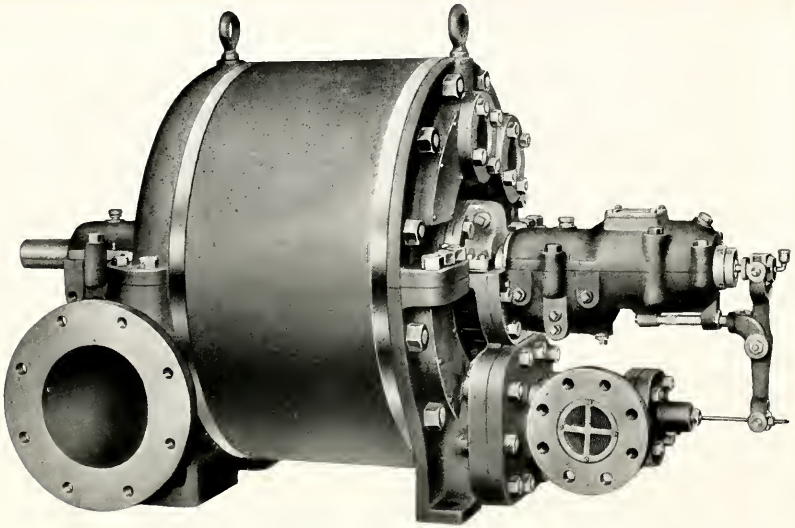
In no prime mover is it safe or good practice to depend upon a single governing device. All De Laval class "C" turbines have a second speed limiting device or emergency governor. This consists of a radial bolt set in a disk and under centrifugal force, acting against a strong spiral spring. When a predetermined speed is exceeded this bolt will project and strike a small lever, tripping a mechanism which immediately closes a butterfly valve in the steam inlet opening. This emergency governor and valve are entirely independent of the speed governor and governor valve and come into action whenever a certain speed is exceeded, regardless of the action of the speed governor.

For connecting the turbine shaft to that of the driven machine, the De Laval flexible

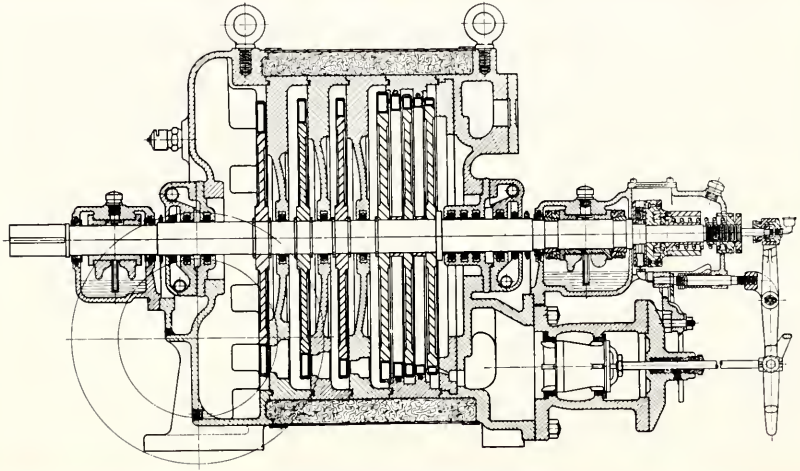
coupling is used, consisting of twoforged steel disks ground and polished on all surfaces,the driving half being fitted with a number of rigid studs which project into corresponding holes in the driven half of the coupling. The torque is transmitted through steel lined rubber bushings, which allow for small defects in alignment and supply the necessary flexibility to prevent strains upon the shaft or bearings. The couplings can be disconnected quickly after which either shaft may be removed without disturbing the other. Each half coupling is mounted on a taper, being prevented from turning by Woodruff keys and is secured in place by lock nuts.

SPECIFICATIONS OF THE KERR ECONOMY TYPE "K" STEAM TURBINE.

The type "K" steam turbine is of the single velocity stage. One set of nozzles,three rows of revolving buckets and two rows of stationary buckets constitute the entire nozzling and bucketing of the turbine.



Type "KR" Kerr 'Economy' Turbine



Section through Type "KR" Turbine

Steam is admitted to the turbine through a double seated balanced governor valve. Expansion then takes place in nozzles reamed in a nozzle ring casting. This expansion resulting in a velocity sufficient to carry the steam through the revolving stationary buckets to the turbine exhaust.

The rotor is made up of a steel shaft upon which are mounted three bucket disks and governor connections.

The bucket disks which are made of a high grade steel are accurately bored and shrunk on the shaft, the shrink fit being such as to positively assure the disks being tight on the shaft when operating at 50% over speed. Each bucket disk is drilled and slotted to receive the shanks of the buckets.

The revolving buckets are drop-forged from nicket steel of the best quality obtainable for the purpose and are of shape that has given the highest efficiency. The hard oxidized skin of the metal in this drop-forged bucket is not subject to erosive action and rust from the steam

and for this reason is far superior to any bucket depending upon machined surfaces. The bucket shanks are inserted inthe rim of the bucket disk and riveted, so that the buckets cannot work loose with this con$truction.

The stationary buckets are made of a special extruded bronze. The bucket shanks are inserted into a dove-tailed channel in the cast iron intermediate holder and are properly spaced by means of dove-tailed distance pieces.

The governor is of the spring loaded centrifugal type consisting of semi-annular weights mounted directly on the shaft, and acting through suitable connections upon the steam valve stem. The parts are enclosed by a cast iron casing, the upper half of which can be readily removed to allow inspection of the governor parts.

Leakage of steam along the shaft at the steam and exhaust ends is prevented by carbon rings having a few thousandths running clearance on the shaft and ample radial clearance in the packing cases. The carbon rings are held in place and prevented from rotating by annular springs and stops.

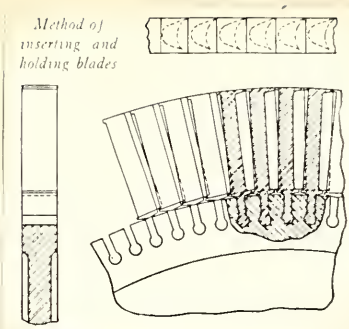


Fig. 7—Section through Disk.

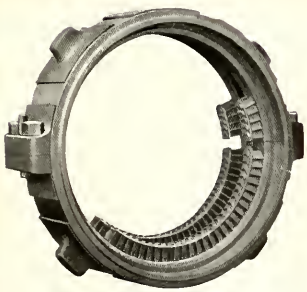


Fig. 4—Intermediate Holder with Buckets

Fig. 3—Disk with Buckets.

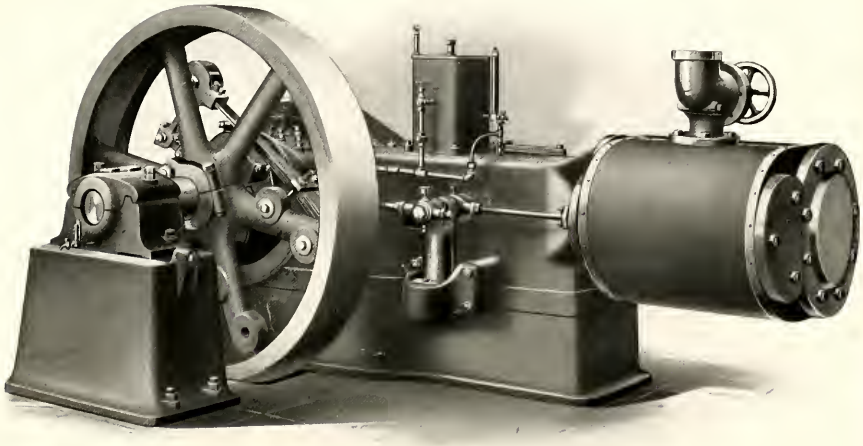
SIMPLE ENGINES.

This equipment is to consist of four types of engines, namely a vertical piston valve engine, marine engine, non-releasing corliss engine and horizontal piston valve engine. They are to be used as a means of studying the construction and operation of steam engines and have therefore been selected for their simplicity and arrangement of valve control.

The specifications of the engines having these requirements are given in brief on the next few pages.

SPECIFICATIONS OF BALL HORIZONTAL LOCK RING VALVE ENGINE.

The tendency toward greater efficiency in the power plant has brought into use high pressures and superheat which were rarely met with a decade ago. To meet these conditions the ball lock ring valve was designed. It is perfectly balanced and of such form that it will not warp under high pressures and temperatures.

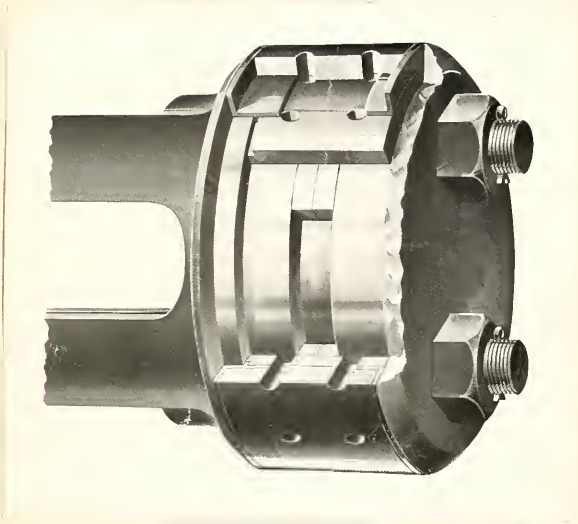


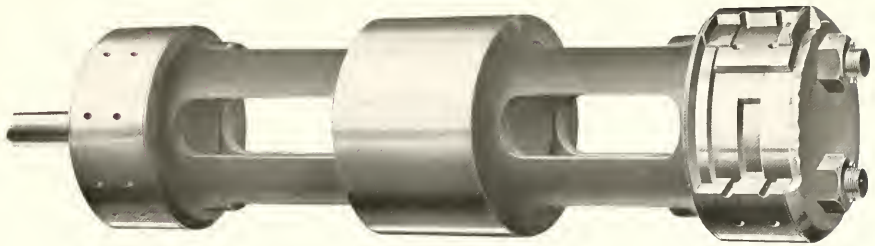
Horizontal Belted Engine, with Subbase and Pedestal, Showing Oiling System

By referring to the illustration it will be noted that the valve consists of a wide outer and a wide inner ring, two lock rings and two spring rings. The steam and the exhaust lock rings are made of steel to avoid breakage. The wide inner and outer rings are made of close grained cast iron having exceptionally good wearing qualities. The spring rings are made of tempered steel and are arranged to give the inner and outer rings an outward pressure which is uniform over the entire circumference. The expansion of these spring rings is sufficient to automatically take up all the wear that naturally occurs during several years of service.

The central portion of the valve is made to fit the sleeve which forms the valve seat and makes an ideal guide, with large wearing surface, carrying the weight of the valve and preventing wear on the rings. The effect of this feature is to add many years to the life of the valve.

It will be noted from the general view of valve and cylinder that the bushings which form the valve seat do not come together at the center.





The Ball Lock Ring Valve

Into the recess formed at this point the cylinder oil is fed by a forced feed lubricator. The Oil is forced between the bushings and central portion of the valve, lubricating it thoroughly and is then picked up in a finely divided condition and passes with the steam over the valve rings into the cylinder.

The exhaust edges are at the outer ends of the valve, so that the valve stem stuffing box must be packed only against the exhaust pressure, instead of against full steam pressure as is necessary with most other forms of valve.

Neat and substantial reducing motions for taking indicator cards are provided with these engines, when ordered. They are so designed that it is not necessary to leave off the side plates on the engine when using them. They give a correct reduction of the motion and means are provided for conveniently connecting and disconnecting them when taking cards.

The shaft governor is used to control this type of engine and is universally recognized as being the most simple and efficient governor ev-

er built.

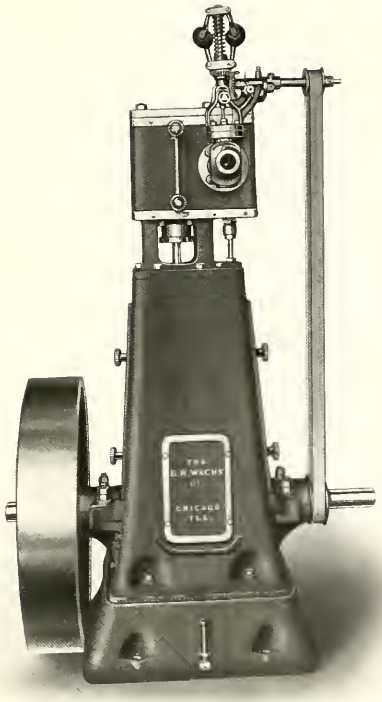
Numerous tests on the ball lock ring valve engine have shown unusual steam economy for a machine of the single valve type. This is due to the perfect tightness of the valve, the steam jacketed cylinder heads, efficient cylinder lubrication and a reduction of heat transference and radiation losses made possible by the design of the cylinder.

The Fleming Harrisburg engine which is now operating in the power plant at the Armour Institute is to be used as a non-releasing corliss engine.

SPECIFICATIONS OF WACHS TYPE E VERTICAL CENTER CRANK ENGINE.

The frame is of the vertidal center crank type having the crosshead guides, which are of the bored type, cast in same. The frame is of box form and of large proportion, having approximately straight sides.

An oil reservoir of large capacity is fitted into the upper end of the frame; this receives oil from the circulating pump, noted later.


THE
G. H. WICHS
CO.
CHICAGO
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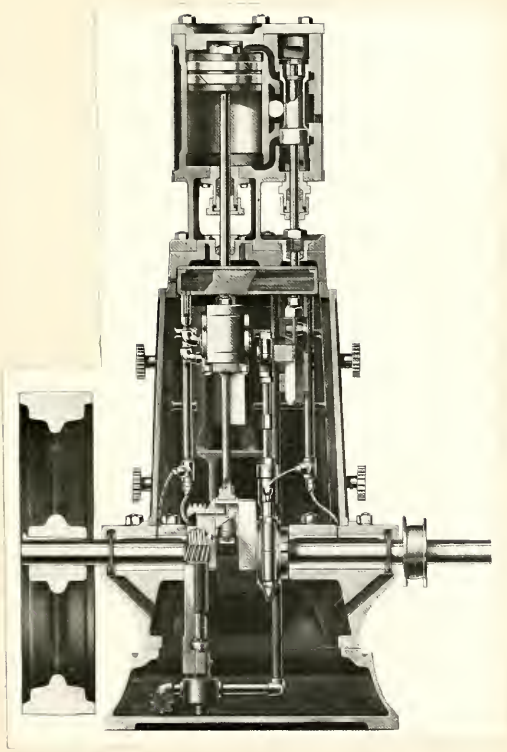


The cylinder and steam chest are cast integral, of cast iron. The cylinder is arranged for a piston valve, the bore of which is accurately machined and counterbored above and below the extremes of valve travel, so that the valve overtravels its counterbores. The valve bore is located as close to the cylinder bore as possible, so that the ports and passages between are of minimum clearance volume and steam friction. The throttling governor is attached directly to the steam chest and an exhaust companion flange is furnished.

The piston is of box form, but is made as light as possible, consistent with ample strength and fitted with two snap piston rings.

The valve is of the piston type and is made of semi-steel. It is accurately ground to size and further lapped to a steam tight joint in its bore. Steam and exhaust edges are accurately finished and sharply defined.

The lubrication for all reciprocating or rotating parts, except the piston and valve is entirely automatic. It starts at the first revolution of the engine and continues automatically un-

til the engine comes to rest. It is of the gravity type and comprises a valveless rotary positive pump, which is submerged in oil in the engine base. This pump is mounted on a bracket attached to the engine frame and is positively driven by means of a spiral gear attached to the crank shaft of the engine. Lubrication for the cylinder and valve is provided by a hydrostatic, sight feed cylinder lubricator of large capacity.

Each engine is furnished with a Gardener wide range throttling governor, governor belt, hydrostatic sight feed cylinder lubricator, regrinding throttle valve, oil gauge with drain, cylinder drain valves and operating wrenches.

THE STEAM CALORIMETER.

Before the recent improvements, barrel or tank calorimeters have been exclusively used. These instruments, however to give results, accurate within one-half percent, require errors in temperature to be less than one-sixth degree and errors in weighing to be less than one-twentieth of a pound. Such measurements being impossible to

make, the results obtained were very irregular and uncertain, and in fact in many cases positively misleading.

With the improved calorimeters, uniform and accurate determinations of the amount of moisture can be made without any special skill on the part of the operator. The instruments are small, readily transported and involve no complicated calculations to secure accurate results.

The throttling calorimeter serves for determining the amount of moisture contained in saturated steam. It consists essentially of a small vessel of about 3 inches in diameter, to which steam is supplied through a tapering or converging orifice, and which contains in its center a very deep cup, into which a thermometer can be inserted for obtaining the temperature of the steam in the calorimeter. The instrument is furnished with a small lever handle cock, to which a U-tube mercury gauge is to be attached for indicating the pressure in the interior. The exhaust steam is discharged from the lower part of the calorimeter and need not be condensed. It may be conducted away in a

Schaeffer & Budenberg Throttling Calorimeter

PATENTED.

(Designed by Professor R. C. Carpenter.)

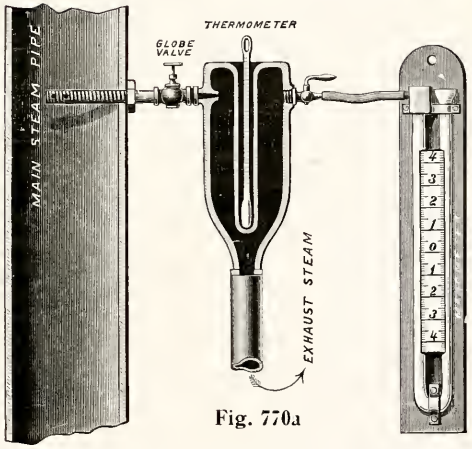


Fig. 770a

hose or pipe, or permitted to escape into the atmosphere, as convenient. As shown in sectional view of the calorimeter attached and ready for use, a globe valve serving for turning on and shutting off the supply to the instrument proper, connects to the collecting nipple which is screwed into the main steam pipe.

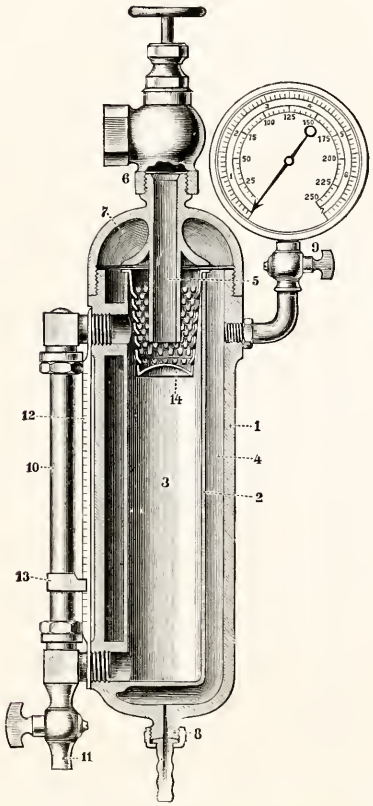
While in the throttling type of calorimeter the amount of water contained in steam is determined by measurement of the heat. The separating calorimeter is designed to show the percentage of water by mechanical separation of the water from the steam.

The separating calorimeter consists essentially of two vessels, one being interior to the other, the outer vessel surrounds the interior one so as to leave a space which answers for a steam jacket. The interior vessel is provided with a water gauge-glass and a graduated scale. The sample of steam the quality of which is to be determined is supplied through the pipe into the upper portion of the interior vessel. The water in the steam is thrown downward into the cup together

Schaeffer & Budenberg
Improved Separating Calorimeter

PATENTED.

(Designed by Professor R. C. Carpenter.)



with more or less of the steam, the course of the steam and water isthen changed through an angle of nearly 180 degrees, which causes the greater weight of water to be thrown outward through the meshes in the cup into the space below in the inner chamber. The cup serves to prevent the current of steam from taking up any moisture which has already been thrown out by the force of inertia. The meshes or fins project upward into the cup, so that any water intercepted will dip into the chamber, the steam then passes upward and enters the top of the outside chamber. It is discharged from the outside chamber through an orifice of known area, in the bottom part, which is much smaller than any section of the passages through the calorimeter, so that the steam in the outer chamber suffers no sensible reduction in pressure by passing through the calorimeter. The pressure in the outer chamber being the same as in the interior, has the same temperature and consequently no loss by radiation can take place from the interior chamber except that which takes place from the

exposed surface of the gauge-glass and which is so slight as to be neglible.

The pressure in the outer chamber and also the flow of steam in a given time is shown by suitably engraved scales on the attached gauge. This scale for showing the flow of steam is the outer one on the gauge. It is graduated by trial and indicates the weight of steam discharged in ten minutes of time.

DYNAMOMETERS.

Heretofore nothing has been said as to the means for measuring the power of the various units in the laboratory. In making experimental tests on these units it will be necessary to have some form of power measuring instrument connected with each of them.

Now there are two kinds of power measuring instruments or dynamometers as they are more generally called. They are namely, those absorbing by friction the power they measure and dissipating it in the form of heat, called ab-

sorption dynamometers, and those transmitting or passing on the power and wasting only a small proportion of it in friction, called transmission dynamometers.

The distinctive utility of the absorption dynamometer as compared with that of thetransmission dynamometer is readily manifest since the one measures power developed whereas the other measures power used. In very rare instances it is possible to utilize the power developed by a prime mover on the test floor, in which case the transmission dynamometer can be economically used, but in most all cases it is necessary to destroy the power developed at the same time that it is measured and for such tests the absorption dynamometer is a necessity.

Since the transmission dynamometer will have so little application in the steam laboratory, it will be entirely omitted and the absorption type of dynamometer will be the only one considered. The three kinds of absorption dynamometers to be used in connection with the various units in the laboratory are, namely the "Froude" dynamometer, of the hydraul-

ics friction type; the Sprague electric dynamometer; and the well known Prony brake dynamometer of the solid friction type.

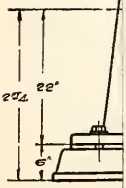
The "Froude and the Sprague" dynamometers will only be used on the turbines and high speed engines and the Prony brake dynamometer being applied to all the other engines.

FROUDE HYDRAULIC FRICTION DYNAMOMETER.

The "Froude" dynamometer, whether it be employed for determining the exact capacity of a rotary prime mover at one or more different speeds, or as an instrument in testing development work, and whether it be employed continuously or intermittently, has proved itself where and whenever employed, as a machine of general commercial utility, and has numberous advantages.

Attention is drawn to the most outstanding of these advantages. Of first importance is the accuracy of the "Froude dynamometer which is scientifically absolute, Of the entire reaction produced by the machine during its operation, almost the whole is hydraulic, so that, at starting,

Type A Engr



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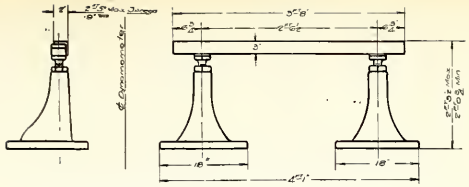
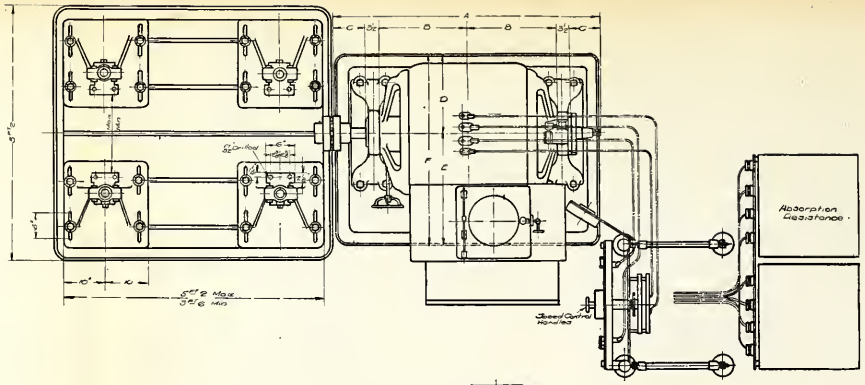
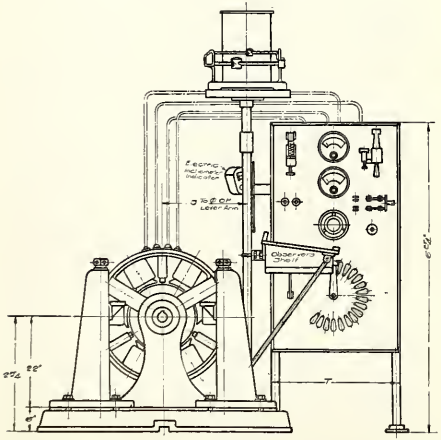
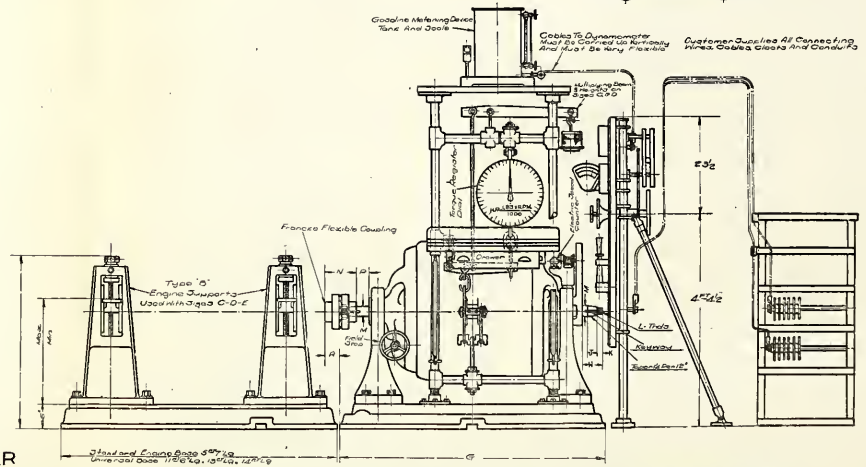


Type A Engine Supports Used With Size A-B






Gasoline Metering Device Tank And Scale
Cables To Dynamometer Must Be Carried Up Vertically And Must Be Very Flexible
Customer Supplies All Connecting Wires, Cables, Cleats And Conduits
Frances Flexible Coupling
Type 'B' Engine Supports Used With Sizes C-D-E
L. Theta
Keyway
Keyway

SPRAGUE ELECTRIC DYNAMOMETER
LAYOUT LABORATORY TEST INSTALLATION

Size	HP	Torque	RPM	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T	Keyway	Absorption Resistance Universal Beam	Width	Weight
A				38½	19½	6¼	17	22	39	61	4	2¼	1	1¼-12	1½	7⅞	3	2⅝	15⅜	24	⅜ × ⅜			
B				38½	19½	6¼	17	22	39	61	4	2¼	1	1¼-12	1⅝	7⅞	3	2⅝	15⅜	24	⅜ × ⅜			
C				63½	21⅜	6½	17½	27	44½	63½	4¼	2⅜	1¼	1⅝-8	2⅜	7⅞	3	3⅛	15⅜	24	½ × ½			
D				81⅜	30½	6½	17½	27	44½	64	4⅝	2⅝	1½	1⅞-8	3	8½	3	3⅜	21	28	⅝ × ⅝			
E				85½	31⅜	7½	17½	27	44½	64	5¼	3	1½	2⅛-8	3	9⅜	3	3⅝	21	28	⅝ × ⅝			

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this resistance is almost negligible, but with increase of speed the resistance is rapidly increased. The capacity range is large with all sizes and types of machine, and with many of them the maximum capacity is one hundred times greater than the minumum at the same speed. This large range of capacity is of particular advantage in that one prime mover and may be tested by the same dynamometer at many different speeds. Compared with the total power capacity of any size dynamometer the inertia of the rotor is very slight, and there is therefore no danger of wrecking any part of the prime mover should its operation be suddenly shut down while connected to the dynamometer. During operation the dynamometer produces no noise, and this advantage of silent operation is obvious when the importance of being able to hear usual noises in the prime mover on test is considered. The load transmitted to the Froude dynamometer can be altered whenever desired without shutting down, and the process of shutting down can be accomplished quickly without attention being given to the dynamometer in any way. Due to the lack of necessity of giving anything more than cursory

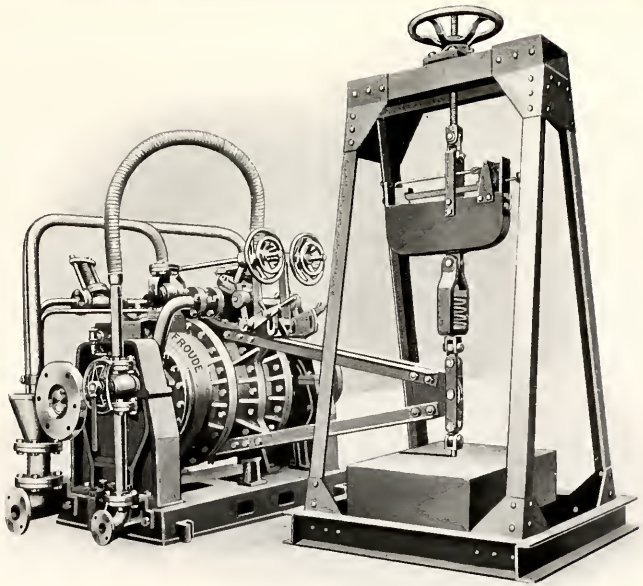


Fig. 10

Froude Reversible Standard Dynamometer of Medium Size Together with Weighing Apparatus.

attention to the "Froude" dynamometer while it is in operation, this machine is particularly suitable for service in connection with long non-stop tests at either full or partial loads. Still another advantage of importance is the fact that the "Froude" dynamometer imposes a pure torque resistance to the prime mover on test and therefore subjects the engine bearings to no resistance for which they are not designed. These several advantages of the "Froude" dynamometer taken together with the many others which it possesses renders it operation a matter of such extreme simplicity, perfect accuracy, and absolute reliability as to make it very desirable in the laboratory.

SPRAGUE ELECTRIC ABSORPTION DYNAMOMETER.

The electrical dynamometer is a very convenient type to use and consists of an electric generator directly coupled to the shaft of the prime mover to be tested. It requires no measuring instruments whatever, except a speed counter, no involved calculations and no skilled attend-

ance. It renders possible quick, easy and accurate measurements of power over a very wide range of speeds and loads. The "Sprague" electric dynamometer has an almost unlimited field of application and the load may be held steadily at any desired point for an indefinite length of time. The resistance in the rheostat is so unchanging that an engine can run the dynamometer for hours at a time with the scale beam "floating" in perfect balance between its upper and lower stops. The dynamometer can be used as a motor, it can return the power generated under certain con i-tions.

These several advantages of the Sprague electric dynamometer together with many others which it passes, renders its service in the laboratory a vital necessity.

"PRONY BRAKE ABSORPTION DYNAMOMETER.

The "Prony" brake dynamometer is an absorption dynamometer of the solid friction type, where in ropes or wooden blocks are applied to

a flywheel, and the tendency of the brake with the flywheels rotation is resisted by weights attached to a lever arm. A system of circulating water is used to dissipate the heat generated.

This type of dynamometer, when in good condition and when given the required constant attention during operation is fairly accurate and sensitive within limits, and is quite convenient. But the great advantage in this type of dynamometer is in its simple construction and application to low speed prime movers.

BLAKE-KNOWLES CONDENSING EQUIPMENT.

The use of condensing apparatus in connection with steam engines and turbines is such universal practice and the principles and advantages of operation are so widely undertook, that the laboratory cannot be complete without them.

A few of the advantages, stated simply and briefly may be mentioned for independent condensing apparatus.

1. They will save from 20 to 30 per-cent in steam when applied noncondensing steam engines or will give an increase of power of corresponding amount.

2. They will quickly produce and will steadily maintain the highest vacuum possible, with the least amount of injection water and with a minimum power to operate the air pump.

3. They require no expensive foundations and occupy but little floor space. They can be readily attached in any position most convenient.

4. Being independently operated, they can be started and a vacuum formed before the main engine is turned over (an important feature), particularly with compound engines having relately small high pressure steam cylinders. The speed of a pump can be readily adjusted to meet the demands of the engine, no matter how variable the load, an impossibility with connected air pumps.

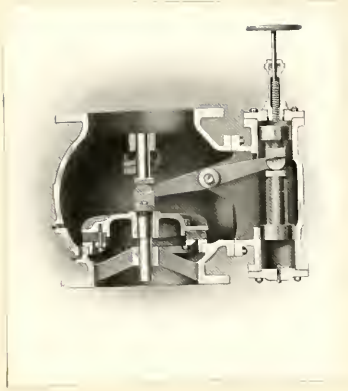
5. They will run smoothly and noiselessly and are always accessible, while the engine is relieved from the heavy drag of carrying a connected

air pump, which is often unnecessarily large, as the general practice is to make connected air pumps of greater capacity than actually required. Besides this, repairs to these connected pumps cannot be made until the engine is shut down (a serious disadvantage).

To each of the turbines and engines not including the simple engines, are to be connected an independent condensing apparatus. All of these condensers are to be of the surface type, and mounted on air and circulating pumps. They are to be placed directly underneath and as close to the engine as possible.

BLAKE-KNOWLES AUTOMATIC EXHAUST RELIEVE VALVES.

They are extensively used in the most modern power plants to meet the demand for a thoroughly reliable and air-tight automatic atmospheric relief, or free exhaust valve. They allow the engine or turbine to exhaust instantly into the atmosphere in case of loss or vacuum due to accident to the condensing apparatus, and are prompt and noiseless in their action.



A safety device of this kind is needed in every steam power plant, whether the condensers are independent or directly connected to the engines. Any condenser is liable to lose its vacuum by the partial or entire stoppage of the supply of injection water, or by the failure of the air pump or its attachments. Under such conditions, the steam in the exhaust pipe accumulates pressure, and is liable to impede or stop the engine before a proper communicationcan be made to the atmosphere. The exhaust steam would probably find relief through the condenser and pump, but not without injuring the valves and packing and being restricted in its passage, it is liable to slow down the engine and often cause a serious damage.

The relieve-valve is to be placed in a branch leading from the main exhaust pipe to the atmosphere. As long as a vacuum is maintained in the condenser, the relief-valve remains tightly closed, but as soon as the vacuum is lost, the valve promptly opens and the engine exhausts into the atmosphere, and continues to run non-condensing until the vacuum is restored, when the valve closes automatically.

A special feature in the design of the "Blake-Knowles" automatic exhaust relief-valve is the dash pot, which allows the valve to open and close quietly(an ordinary check valve would pound from the effect of the engines intermittent exhaust). The facing of this valve is made of a special material, which keeps the valve tight, but doesnot allow it to adhere to the seat.

It will be noted that two steam engines and one steam turbine have been placed on the drawing ofthe steam laboratory and have not been mentioned in this discussion. Due to the fact that at the time of this writing no data had been received pertaining to them, therefore no discussion of them could be given.

PART FIVE.

DESIGN OF STEAM LABORATORY.

The arrangement and piping plan of the steam laboratory as originally laid out has been revised to a great extent. The layout as finally decided upon will be found in the accompanying folder in the back of this thesis.

The building is to be 180 feet long, 100 feet wide and at least two stories high including the gound floor. The ground floor is to be eight feet high and the first floor twelve feet high. This building is to contain the steam and hudraulics laboratories. Stairways leading from one floor to the other have been placed at convenient locations so as to make quick communication between them.

On the ground floor is to be placed the condensing equipment and auxiliary apparatus. On the first floor is to be located the engines and turbines.

The simple engines are to occupy the entire first floor to the right of the crane well.

This equipment is to be operated noncondensing. "Prony" brake dynamometers are to be used for measuring the power developed by these engines.

The other equipment has been carefully arranged on the main section of the first floor. Ample space has been allowed around each unit for working facilities. "Prony" brake dynamometers are to be used on each of the slow speed engines. "Froude" hydraulic friction and "Sprague" electric dynamometers are to be applied to all of the turbines and high speed engines.

On the ground floor is to be located independent condensing equipment and auxiliary apparatus for each of these engines and turbines. The piping system is to be laid out so that these engines and turbines can be operated either condensing or non-condensing. The circulating water is to be taken from a spray pond located just outside of the building.

One atmospheric exhaust for the valve setting engines is to extend to the roof along the rear outer wall of the building and two for the other engines and turbines, one to extend to the roof at each

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end of the front outer wall of the building. There are to be two live steam headers entering the building at the left and extend the entire length of the building under the floor of the main section of the steam laboratory. The heads for the various units are to be taken from one header only. The other header is to be used for emergency and is to be tied in with the first at proper intervals. Suitable piping is to be arranged so that the condensate can be pumped into weight tanks and then to either the main feed water line or to the sewer.

A testing block has been placed in the steam laboratory on which is mounted an absorption dynamometer, to be used for special testing purposes.

PART SIX

DISCUSSION.

When this problem was undertaken it was fully realized that for the short period of time allowed to this thesis work, a complete design of the steam laboratory was impossible. However, it was hoped that more extensive work could have been accomplished, but due to the fact that so much time was expended in research work and in collecting material that little could be done in actual designing. Now that the work has come to a close, it is well understood, that what has been done is really only the beginning. There are many items of importance in the layout of this laboratory, which have been given considerable thought and would have been worked out had time permitted. Among the most important of these is the diagrammatic outline of the piping system.

The time which has been given for this work has been spent in extensive study of the selection and arrangement of the equipment in the laboratory.

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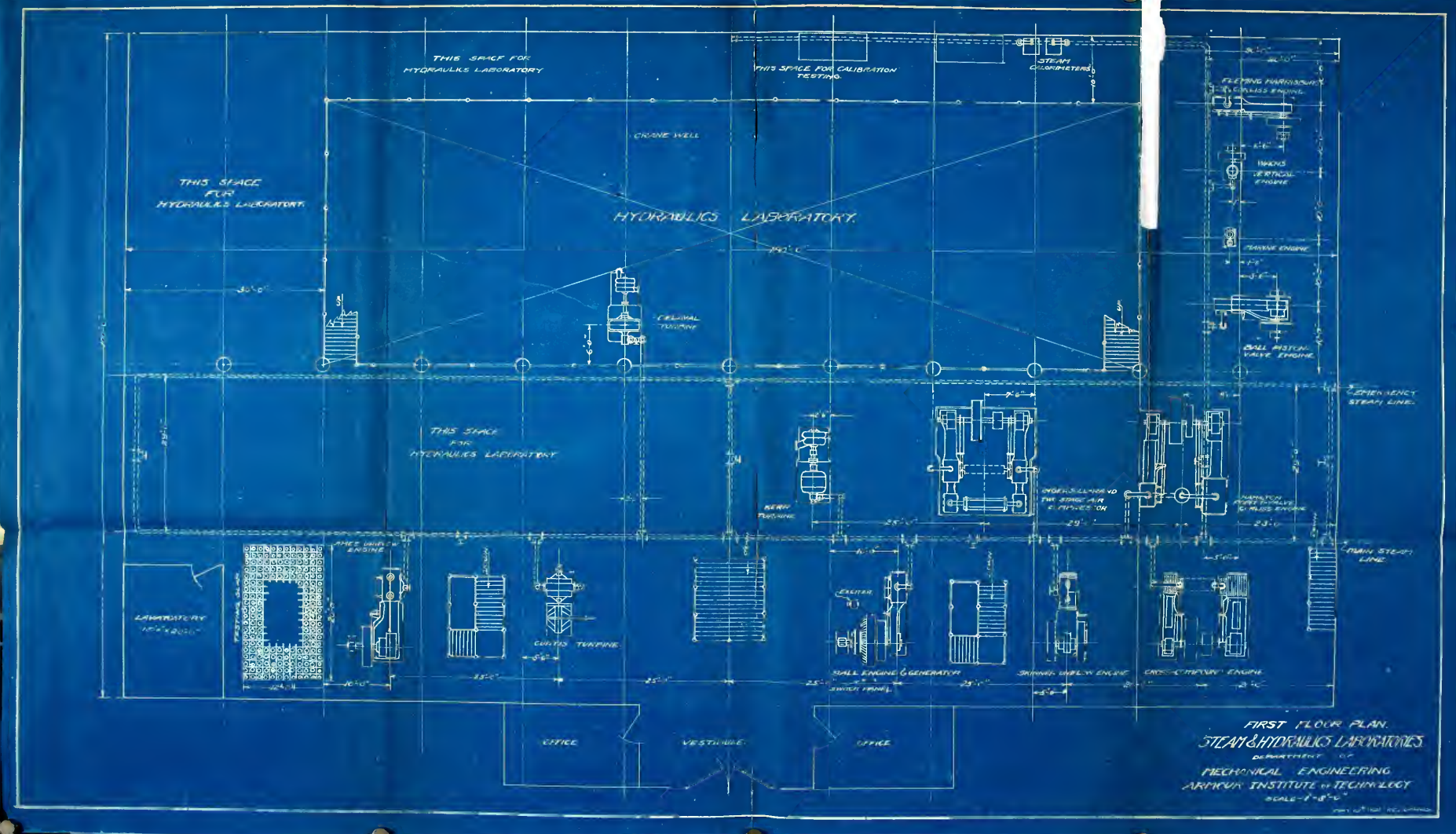
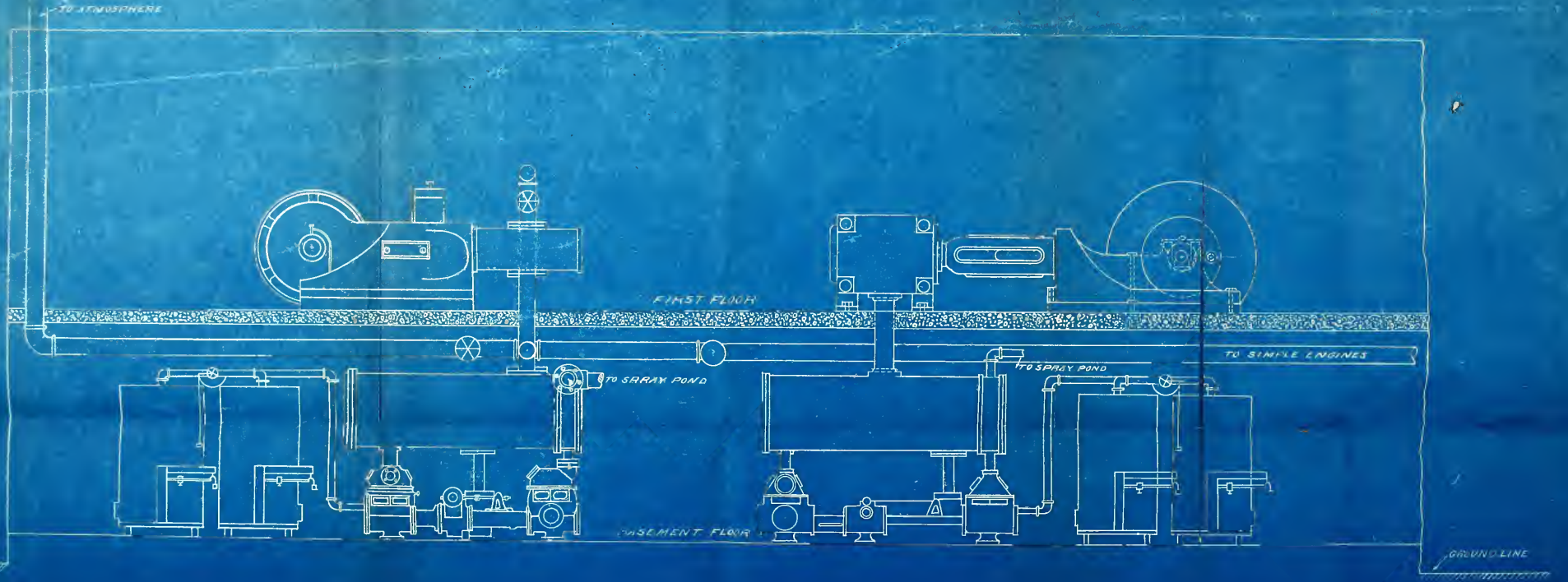


FIRST FLOOR PLAN.
STEAM & HYDRAULICS LABORATORIES
DEPARTMENT OF
MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY
SCALE-1'-8"



END ELEVATION

STEAM & HYDRAULICS LABORATORIES

DEPARTMENT OF

MECHANICAL ENGINEERING

ARMOUR INSTITUTE OF TECHNOLOGY

SCALE: 1"=2'

J. H. CLOUSE

It is hoped that if at any time in the future this problem should be continued some material and ideas can be obtained from what has been accomplished.

PART SEVEN

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